SANE
Spin Asymmetries on the Nucleon Experiment

TJNAF E-03-109

U. Basel, Hampton U., Louisiana Technical U., IHEP Protvino, Rensselaer Polytechnic I., Temple U., TJNAF, U. of Virginia, College of William & Mary, Yerevan Physics I.

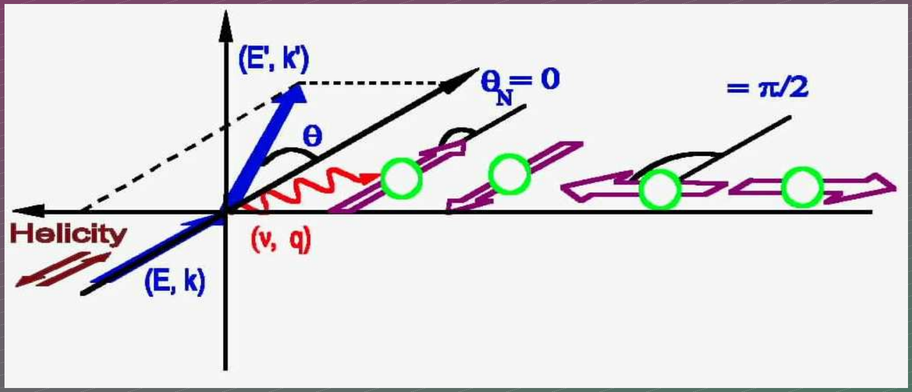
Spokespersons: Seonho Choi (Temple), Zein-Eddine Meziani (Temple), Oscar A. Rondon (U. of Virginia)
(G. Warren (PNNL) - proposal spokesperson)

Physics:

- Measure proton spin structure function $g_2(x, Q^2)$ and spin asymmetry $A_1(x, Q^2)$ at momentum transfer $2.5 \leq Q^2 \leq 6.5$ GeV^2 and Bjorken x $0.3 \leq x \leq 0.8$
- Study x and Q^2 dependence, twist-3 effects, moments of g_2 and g_1, comparison with Lattice QCD predictions, test polarized local duality for $W > 1.4$ GeV,
- Single-arm experiment with large solid angle electron telescope **BETA**

Lepton-Nucleon Polarized Scattering

- General form of polarized scattering



$$\frac{d^2\sigma^{(\uparrow\downarrow)}}{d\Omega\, dE'} - \frac{d^2\sigma^{(\downarrow\downarrow)}}{d\Omega\, dE'} = \Delta\sigma(\vartheta, \vartheta_N, \phi) =$$

$$\frac{4\alpha^2 E'}{Q^2 E}\left[(E\cos\vartheta_N + E'\cos\vartheta) M G_1 + 2EE'(\cos\alpha - \cos\vartheta_N) G_2\right]$$

$$\cos\alpha = \sin\vartheta_N \sin\vartheta \cos\phi + \cos\vartheta_N \cos\vartheta$$

- Nuclear spins parallel or perpendicular to the beam helicity

$$\Delta\sigma(\vartheta_N = 0) = \frac{4\alpha^2 E'}{Q^2 E}\left[(E + E'\cos\vartheta) M G_1 - Q^2 G_2\right] = 2\sigma_U A_{\parallel}$$

$$\Delta\sigma(\vartheta_N = \pi/2, \phi) = \frac{4\alpha^2 E'}{Q^2 E} E' \sin\vartheta \cos\phi \left[M G_1 + 2E G_2\right] = 2\sigma_U A_{\perp}$$

Spin Structure Functions (SSF's)

- SF's at Low Energy (e.g. Resonances): forward virtual Compton scattering

$$A_1(Q^2,\nu)=\frac{\sigma^T_{1/2}-\sigma^T_{3/2}}{\sigma^T_{1/2}+\sigma^T_{3/2}}=\frac{M\nu G_1(Q^2,\nu)-Q^2 G_2(Q^2,\nu)}{W_1(Q^2,\nu)}$$

- Transition from low energy (resonances) to high energy (DIS)

$$\lim_{Q^2,\nu\to\infty}(M^2\nu)G_1(Q^2,\nu)=g_1(x)$$

$$\lim_{Q^2,\nu\to\infty}(M\nu^2)G_2(Q^2,\nu)=g_2(x)$$

$$\lim_{Q^2,\nu\to\infty}MW_1(Q^2,\nu)=F_1(x), \qquad x=\frac{Q^2}{2M\nu}$$

- SF's in DIS: Parton model (and Operator Product Expansion - OPE)

$$A_1(x)\approx\frac{g_1(x)}{F_1(x)}=\frac{\sum e_i^2\Delta q_i}{\sum e_i^2 q_i}$$

Transverse Spin Structure Functions

- Polarized transverse structure function has no simple parton model interpretation
- g_2 is combination of twist-2 and twist-3 components:

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \overline{g}_2(x,Q^2)$$

$$= -g_1(x,Q^2) + \int_x^1 g_1(x',Q^2)\frac{dx'}{x'} - \int_x^1 \frac{\partial}{\partial x'}\left[\frac{m}{M}h_T(x',Q^2) + \xi(x',Q^2)\right]\frac{dx'}{x'}$$

  - *W*andzura-*W*ilczek part depends on g_1; h_T is twist-2 chiral odd transversity
  - ξ represents twist-3 quark-gluon correlations.
- Transverse spin structure function g_T measures spin distribution normal to virtual γ

$$g_T = g_1 + g_2 = \int_x^1 \left[g_1 - \frac{\partial}{\partial x'}\left(\frac{m}{M}h_T + \xi\right)\right]\frac{dx'}{x'} = \frac{\nu}{\sqrt{Q^2}} F_1(x,Q^2)\, A_2(x,Q^2)$$

Transverse Spin Structure Sum Rules

- OPE relates moments of $\boldsymbol{g_1}$, $\boldsymbol{g_2}$ to twist-2 ($\boldsymbol{a_N}$), twist-3 ($\boldsymbol{d_N}$) matrix elements.

$$\int_0^1 x^N g_1(x,Q^2)\,dx = \frac{1}{2}\boldsymbol{a_N} + O(M^2/Q^2), \qquad N = 0, 2, 4, \ldots$$

$$\int_0^1 x^N g_2(x,Q^2)\,dx = \frac{N}{2(N+1)}(\boldsymbol{d_N} - \boldsymbol{a_N}) + O(M^2/Q^2), \qquad N = 2, 4, \ldots$$

- $\boldsymbol{d_N}$ measure twist-3 contributions (for $m << M$ and $\boldsymbol{h_T}$ not too large.)

$$\boldsymbol{d_N(Q^2)} = \frac{2(N+1)}{N}\int_0^1 x^N \overline{\boldsymbol{g_2}}(x,Q^2)\,dx$$

  - Burkhardt-Cottingham
    - not from OPE

$$\int_0^1 g_2(x)\,dx = 0$$

  - Efremov-Leader-Teryaev
    - valence quarks

$$\int_0^1 x\left(g_1^V(x) + 2g_2^V(x)\right)dx = 0$$

Beyond Inclusive Longitudinal Scattering

- Eight distribution functions:
  - quark $\boldsymbol{k}_\perp$ independent (leading twist)
    - F_1, g_1, inclusive
    - δ = transversity
  - quark $\boldsymbol{k}_\perp$ dependent
    - $g_{1T} = g_1 + g_2$, inclusive, mixed twist.
    - $h_{1L}{}^{\perp}, h_{1T}{}^{\perp}$, semi - inclusive, T- even
    - $f_{1T}{}^{\perp}, h_1{}^{\perp}$, semi - inclusive, T- odd

- Spin Dependent Fragmentation: Semi-inclusive Leptoproduction
  - Hadron (π, K,..)-lepton coincidence
  - Semi-inclusive Asymmetries

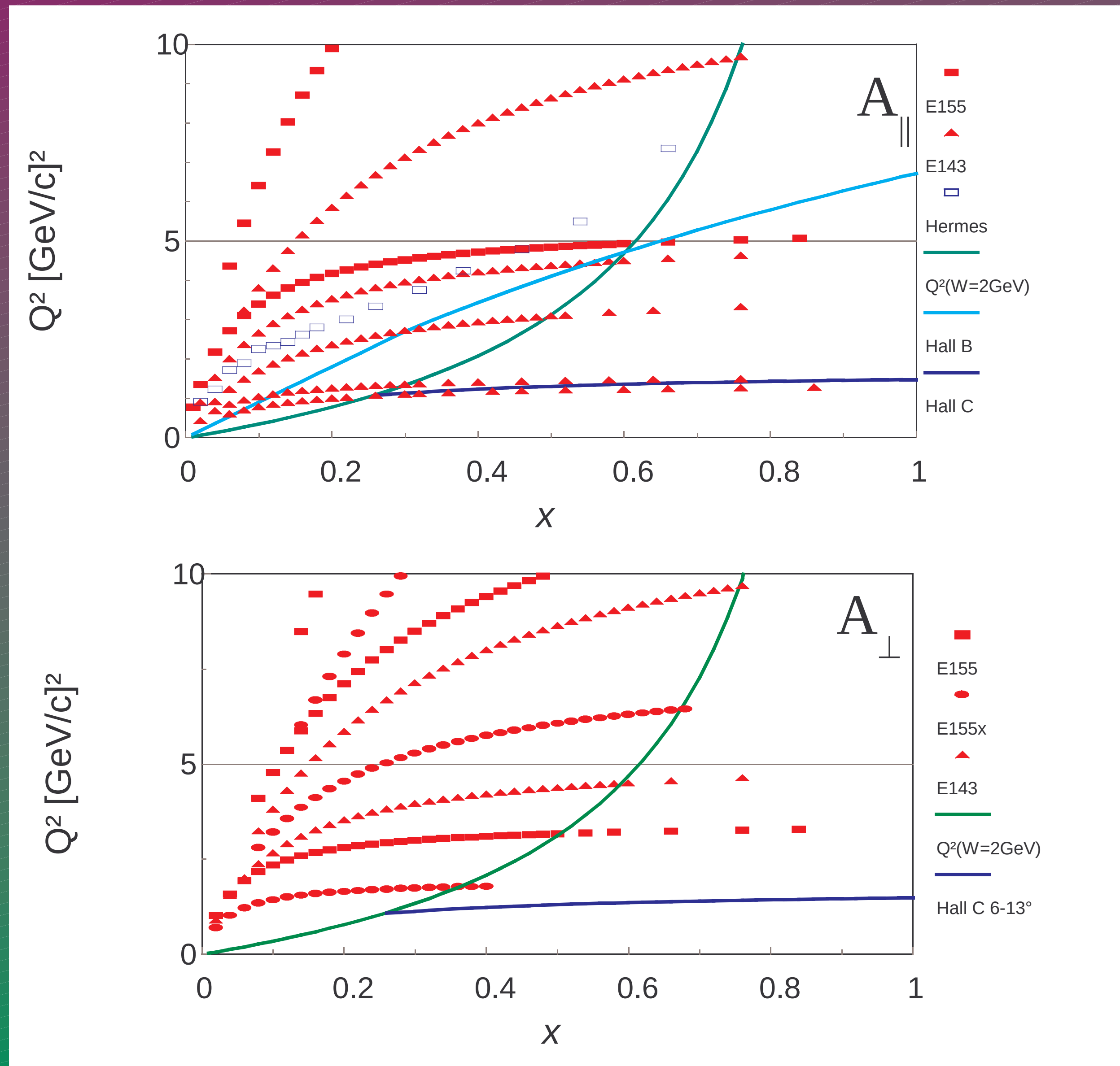
$$A_1^h(x,z,Q^2) = \frac{\sum_f e_f^2 \, \Delta q_f(x,Q^2) \, D_f^h(z,Q^2)}{\sum_f e_f^2 \, q_f(x,Q^2) \, D_f^h(z,Q^2)}$$

$$z = E_h / \nu$$

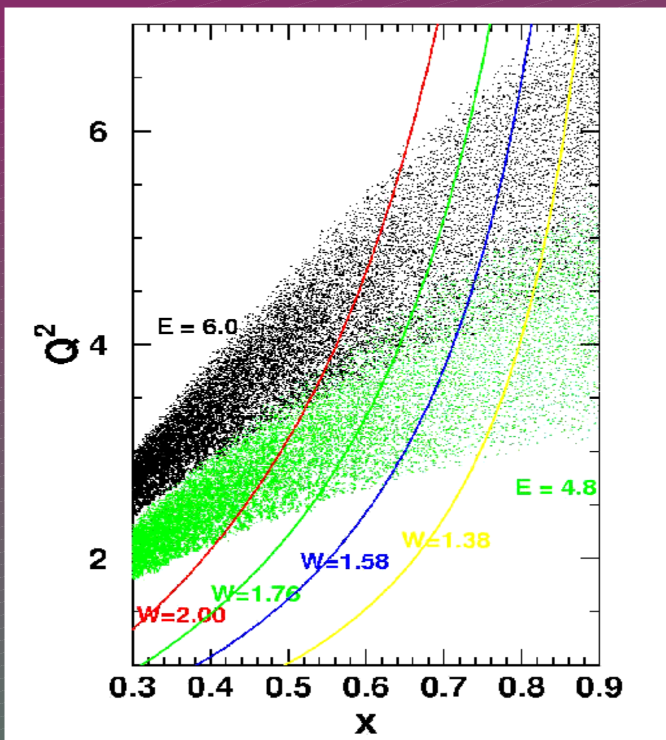
- Spin Dependent Exclusive Scattering:
  - Generalized Parton Distributions

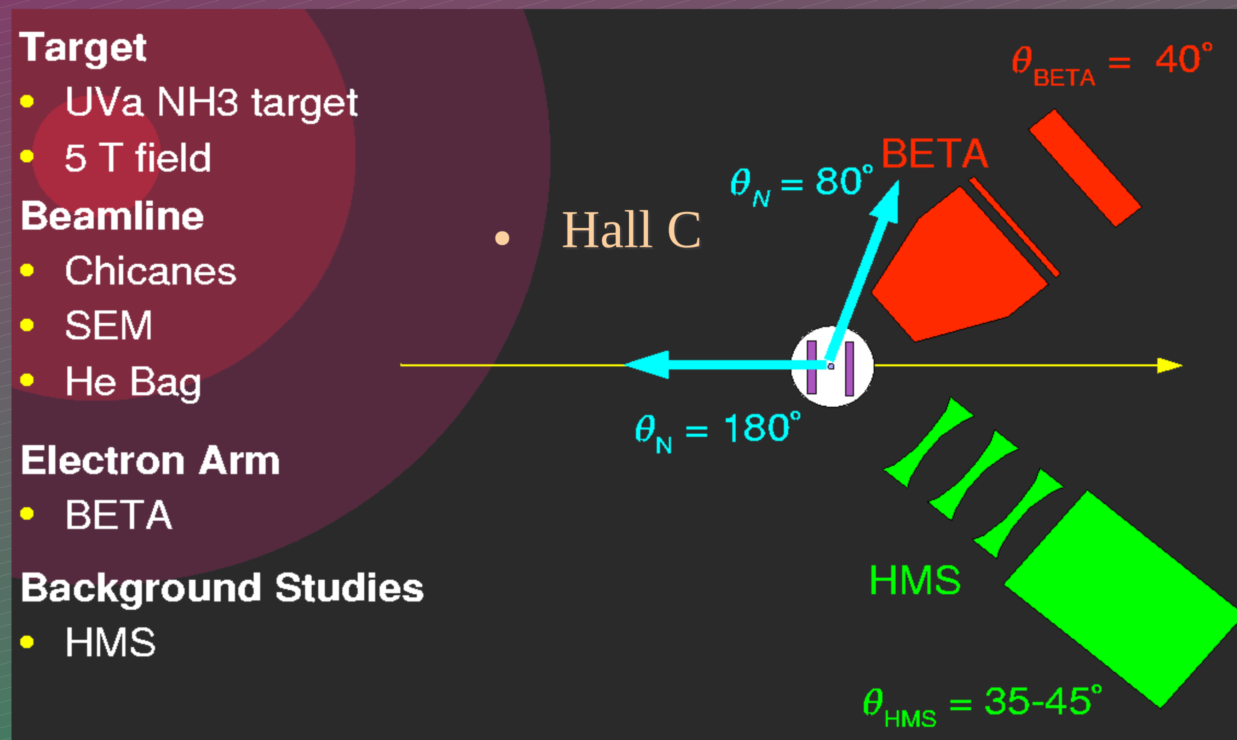
Data on $A_\parallel$ and $A_\perp$: protons and deuterons

- Central kinematics for $A_\parallel$ and $A_\perp$ measurements on protons and deuterons
- $Q^2 \leq 10$ GeV^2
- Data from
  - SLAC
  - HERMES
  - JLab Hall B (upper limit of Q^2)
  - JLab Hall C
  - (SMC data $x < 0.05$ not shown)



SANE Kinematics and Layout

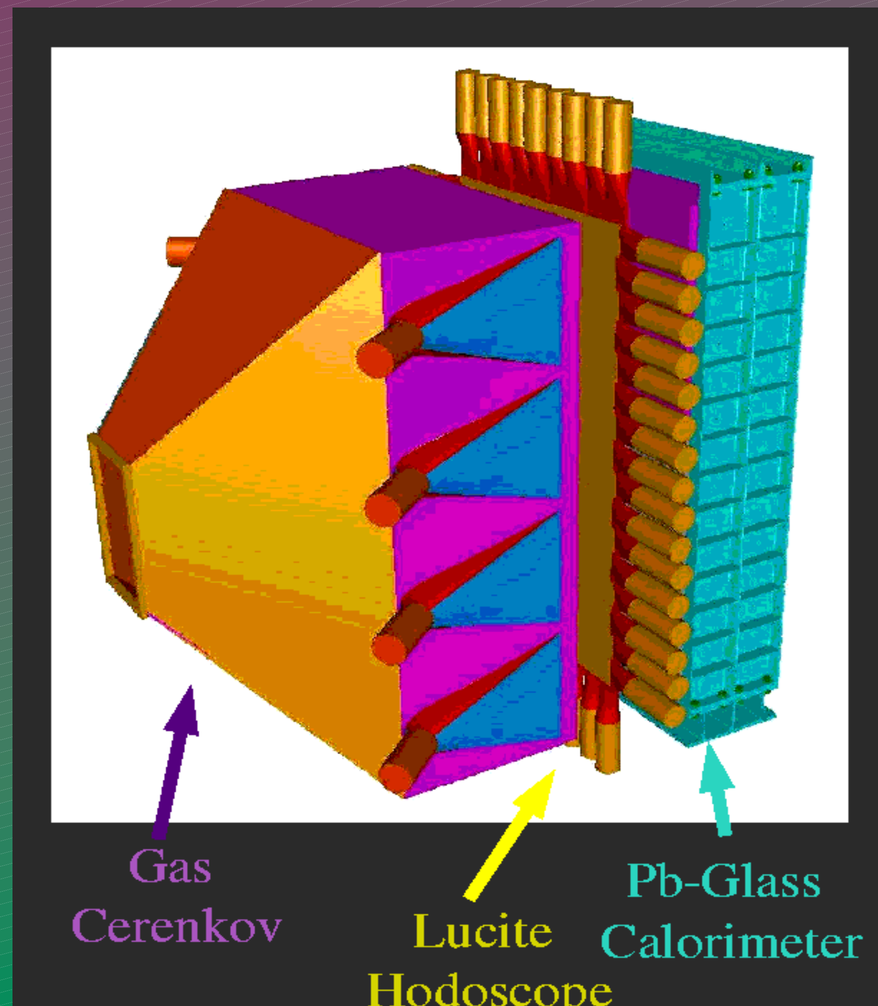




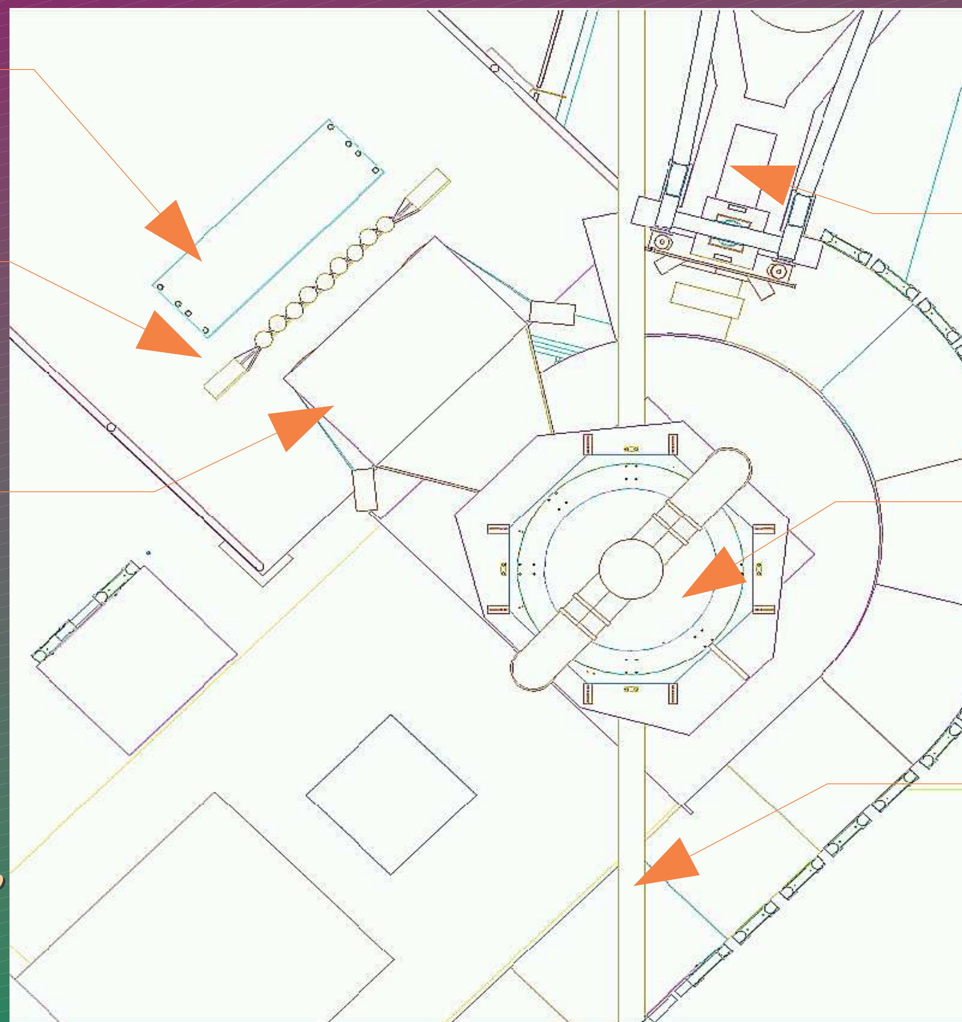
- Two beam energies:
  - 6 GeV (black)
  - 4.8 GeV (green)
- CEBAF polarized beam
  - 85 nA
  - 75% beam polarization

Big Electron Telescope Array - BETA

- Three subsystems:
  - Lead glass calorimeter BigCal: main detector
  - Gas Cherenkov (N): additional pion rejection
  - Lucite hodoscope: tracking
- Target field sweeps low *E* background
- Characteristics
  - Effective solid angle (with cuts) = 0.194 sr
  - Energy resolution $5\%/\sqrt{E}$(GeV)
  - angular resolution = 2°
  - 1000:1 pion rejection



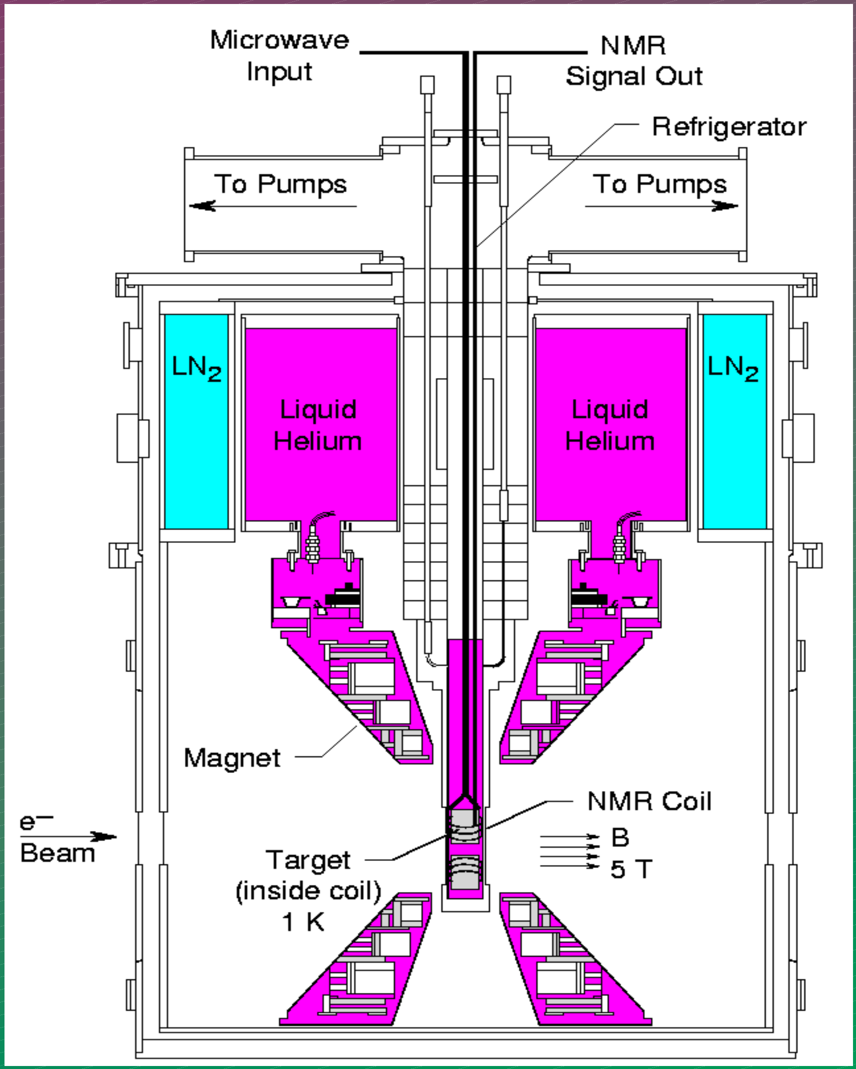
SANE in Hall C



- Lucite Cherenkov:
  - 16 *x* by 8 *y* hodoscope
  - 1.25 cm thick *x*, 2.5 cm thick *y*
- PMT at each end
- reflective wrap: 10 p.e.'s

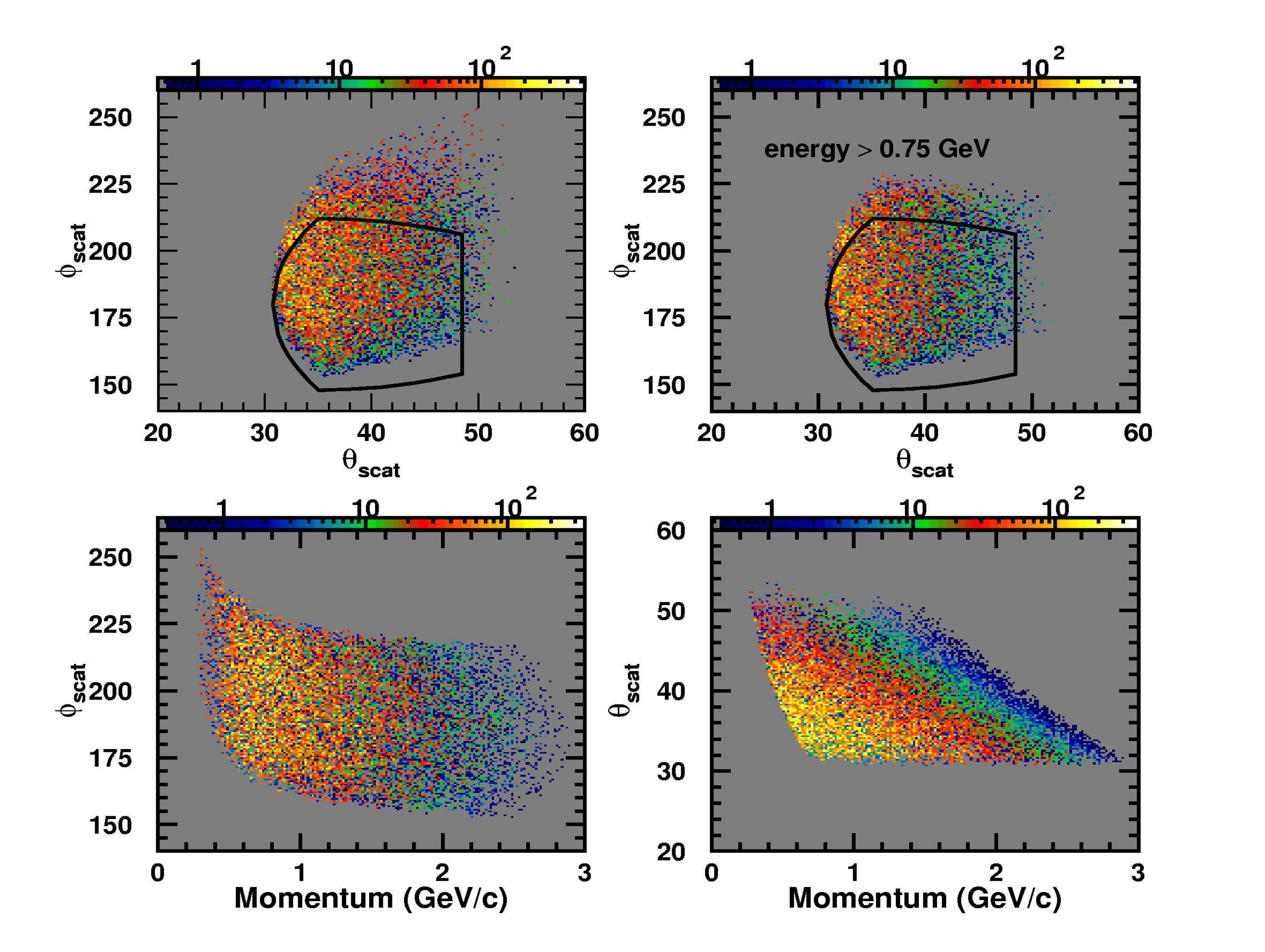
UVa Polarized Target

- Dynamic Nuclear Polarization
- 5 T Field
  - can steer beam
  - affect optics of scattered electrons
- 1 K evaporative refrigerator
- Composite target: N+H+He
  - asymmetry is diluted by unpolarized materials
- Measure target polarization
  - calibration: thermal equilibrium
  - continuous monitoring by NMR

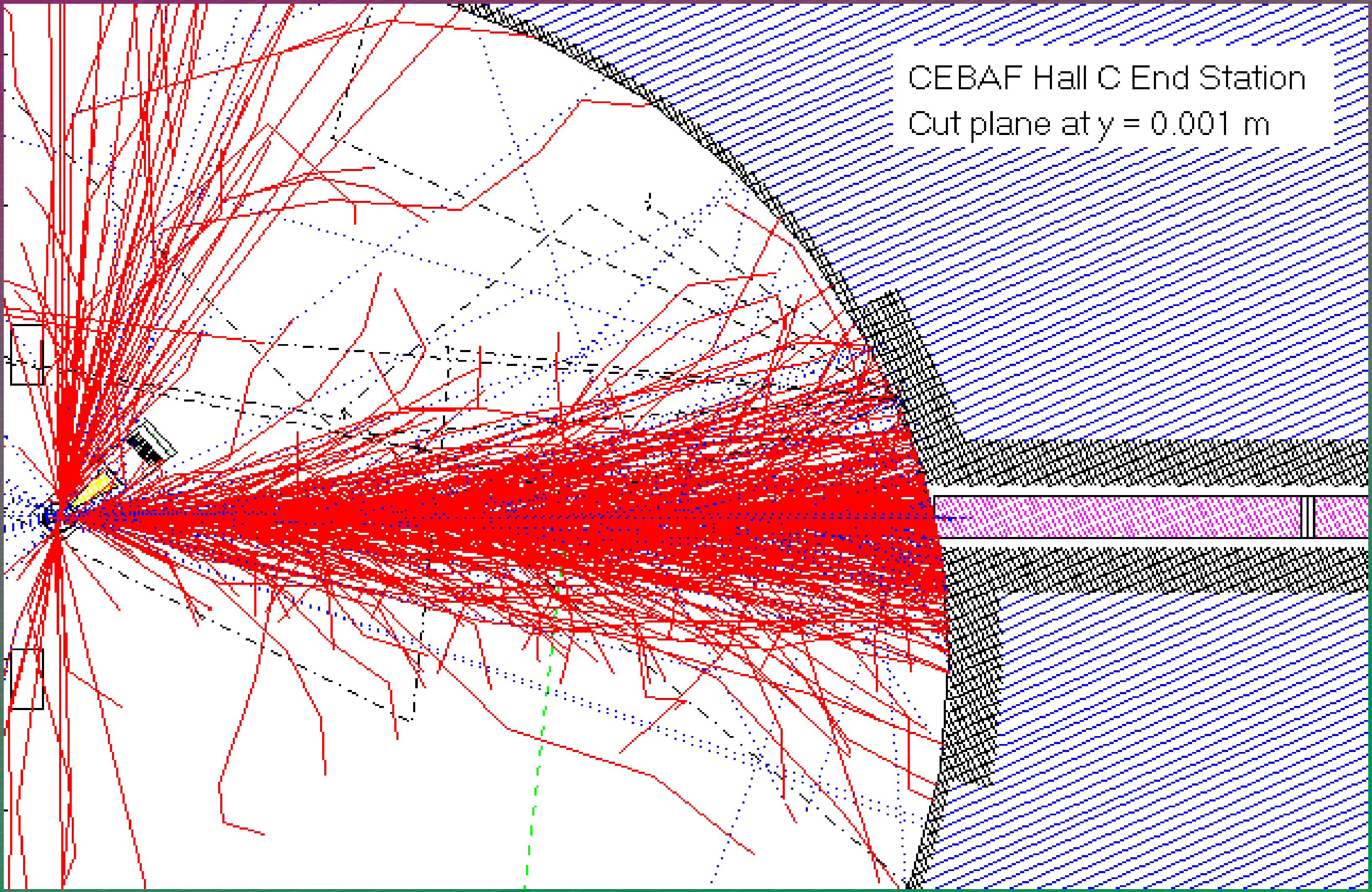


Acceptance: E = 6.0 GeV, $\theta_N = 180^\circ$

- All four kinematics are similar.



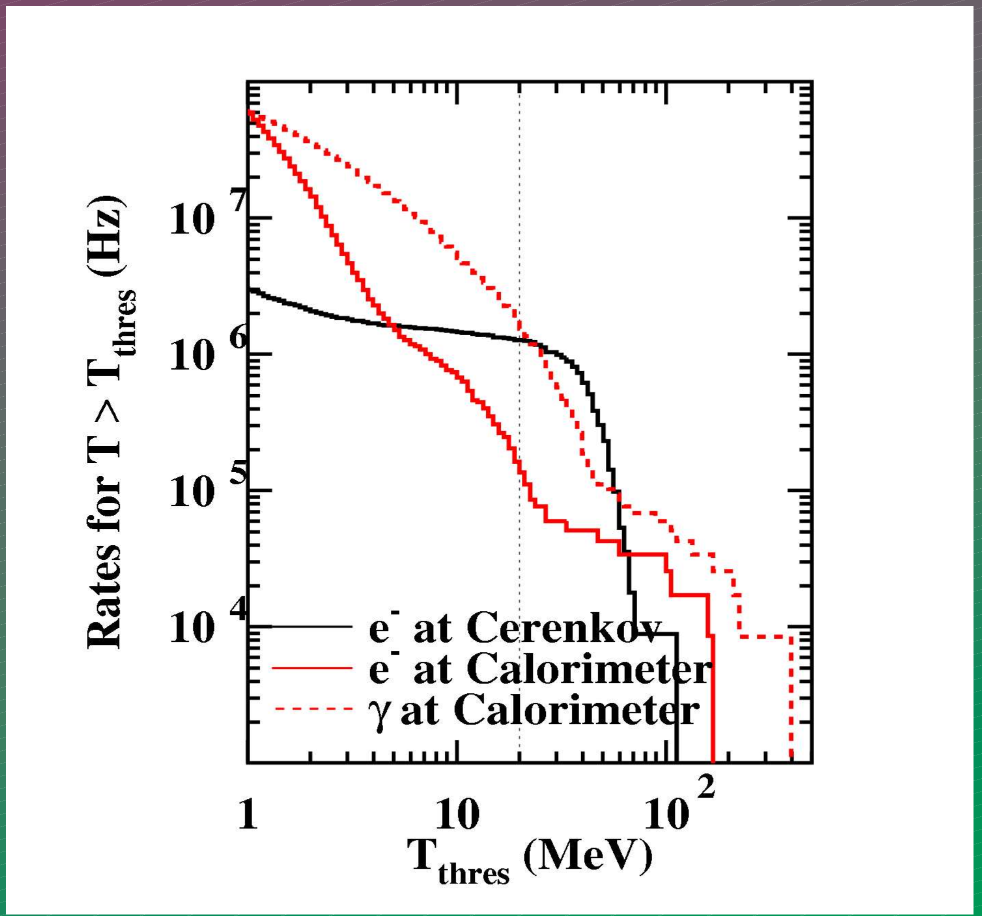
Beam Line Background Studies



Beam Line Background Studies

Conducted preliminary beam line background studies using simulation package of Pavel Degtiarenko.

- *Parallel field:* no problems with BETA at 40°.
- *Transverse field:* a large fraction of electrons escape pathologically into BETA:
  - expect at most 200 kHz/PMT for Gas Cerenkov.
  - Pileup, trigger rates, detector rates all remain manageable.
  - These numbers are conservative... will probably have a reduction of at least 2 in Cerenkov rates.



Rates in BETA

Gas Cerenkov (> 20 MeV)

E	e^-	π^-	Trig
4.8	28.1	242.0	30.5
4.8	1590.0	223.0	1592.2
6.0	25.3	255.0	27.9
6.0	1510.0	236.0	1512.4

Calorimeter (> 900 MeV)

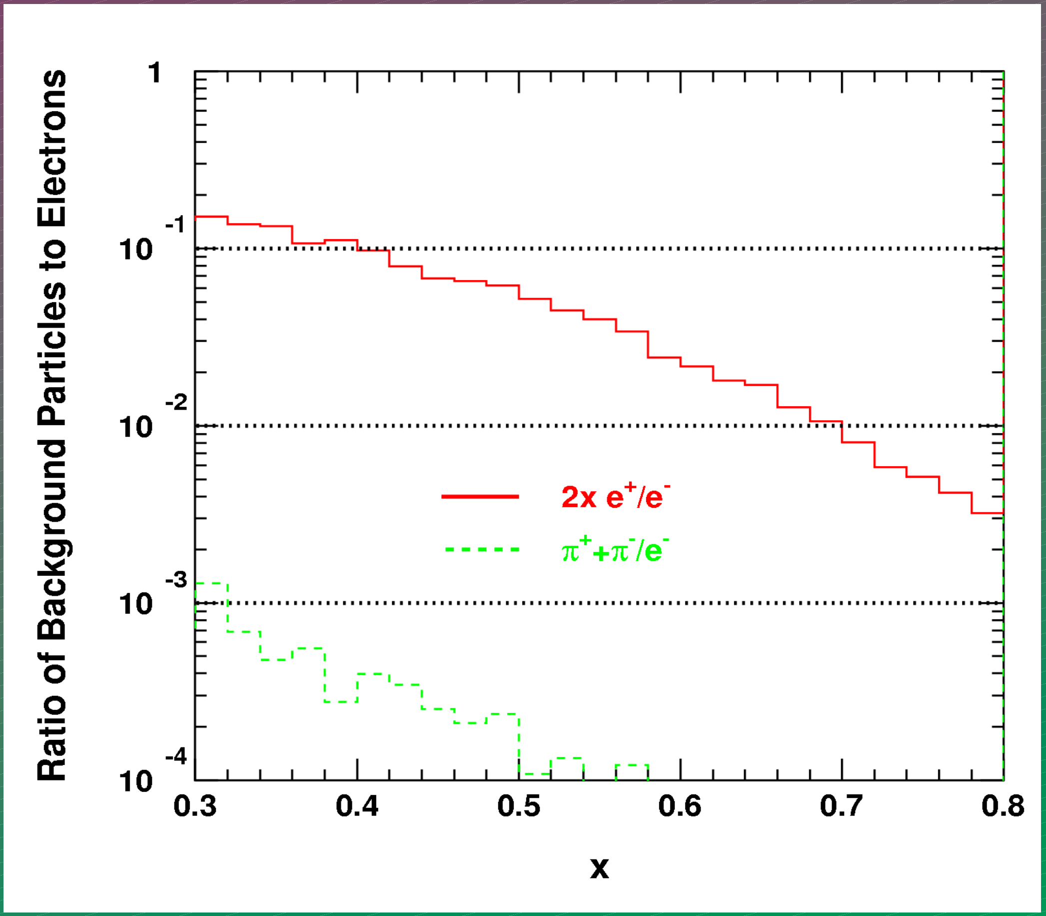
E	e^-	π^-	π°+N	Trig
4.8	0.3	1.0	7.2	8.5
4.8	0.3	1.0	7.1	8.4
6.0	0.3	1.1	8.1	9.5
6.0	0.3	1.2	8.0	9.4

BETA Trigger Rates

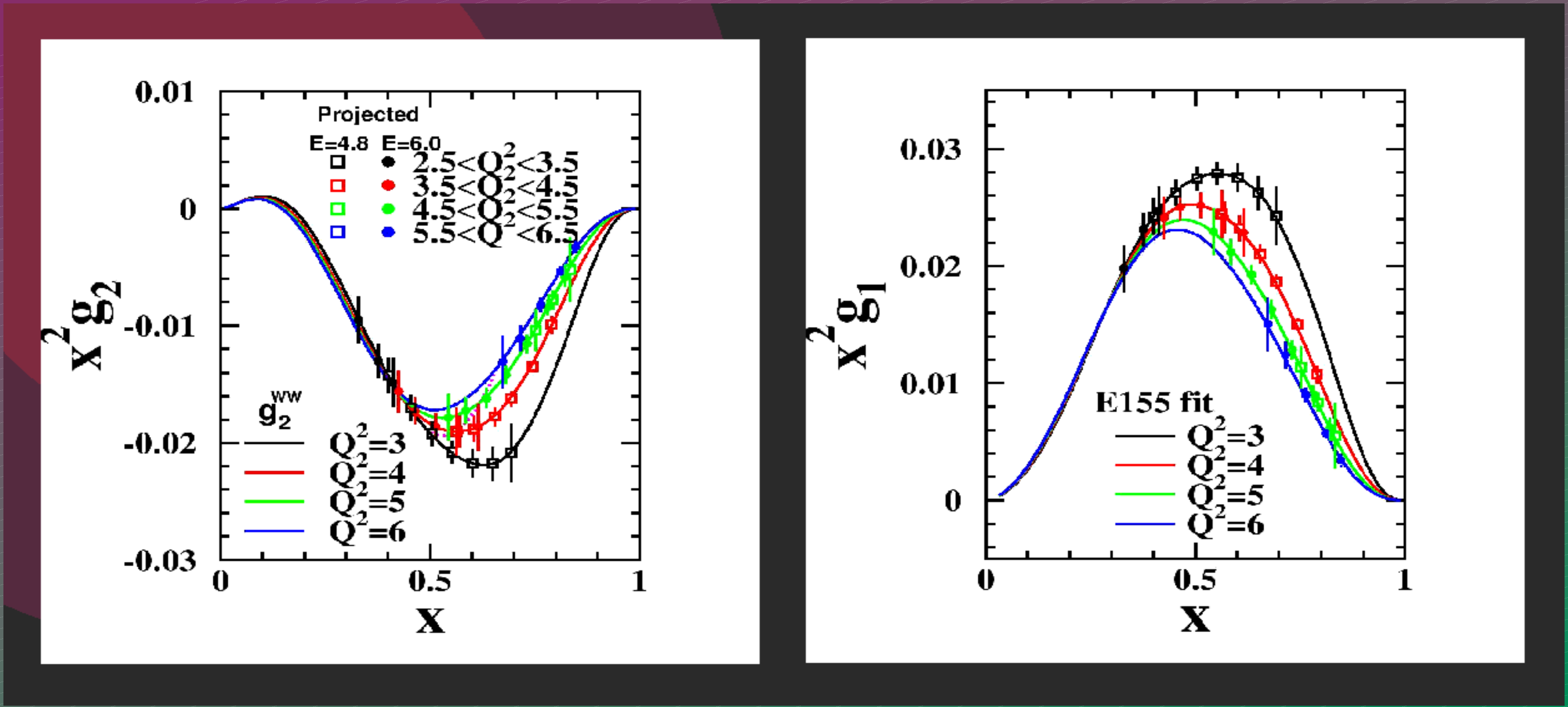
E	True	Accd	offline A/T
4.8	0.31	0.03	0.0%
4.8	0.31	1.34	0.6%
6.0	0.31	0.03	0.0%
6.0	0.31	1.43	0.6%

Background Rates

- Dominated by charge-symmetric processes, mostly $\pi^0 \rightarrow \gamma\, e^+ e^-$.
- Measure ratio of rates in HMS.
- Measure ratio of asymmetries using events with γ, $\gamma\gamma$ and $e^+ e^-$ in BETA and use CLAS data.
- Hadron backgrounds measured by ignoring Gas Cerenkov in trigger.
- Reduce Positron Rates by increasing energy threshold

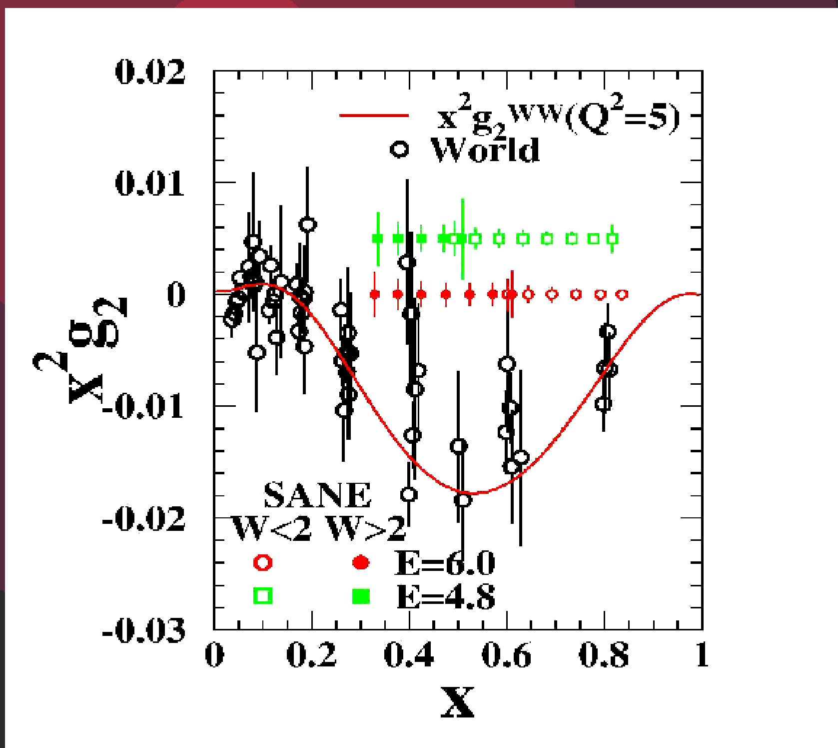


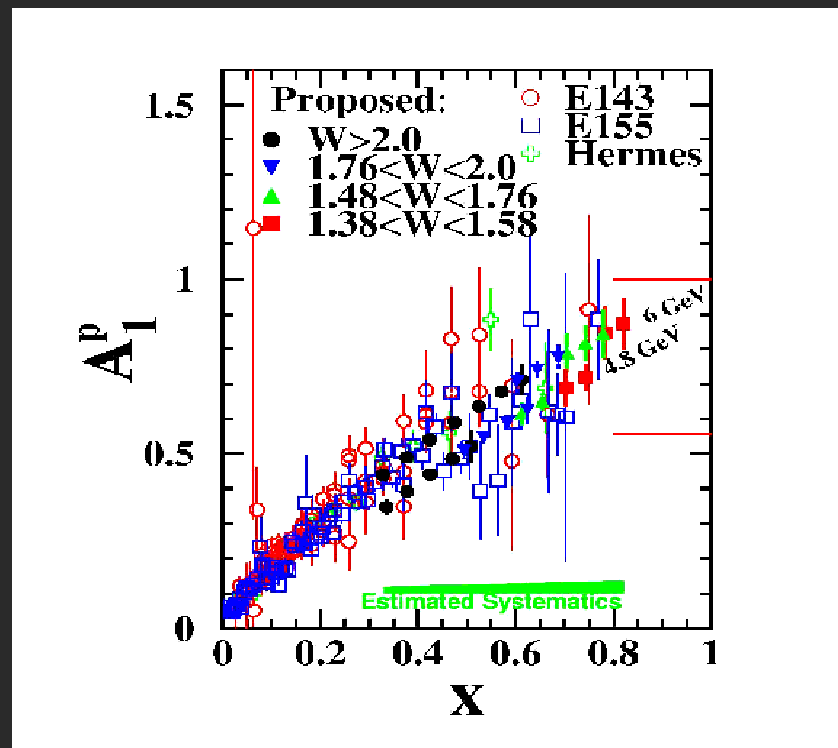
SANE Expected Results



- *x* dependence at constant Q^2 and Q^2 dependence at fixed *x*
- Multiple data points at different Q^2 values for each value of *x*

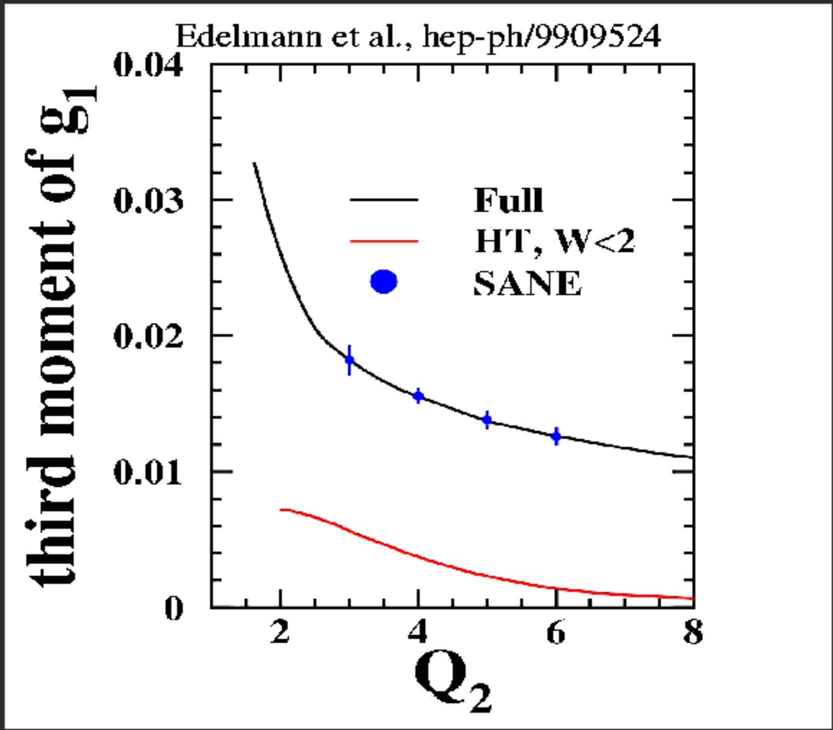
SANE Expected Results (II)

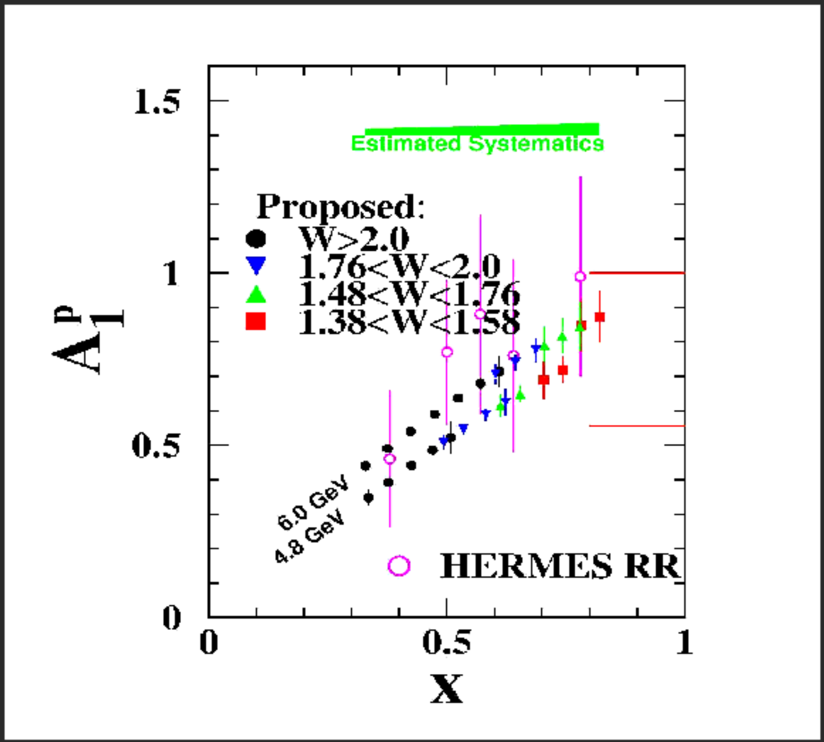




- DIS data up to x = 0.6; Resonances measured down to W = 1.38 GeV
  - g_2 measured in region of most sensitivity for d_2

SANE Expected Results (III)





- Twist-3 matrix element $\boldsymbol{d}_2 = \int_0^1 x^2 (2\boldsymbol{g}_1 + 3\boldsymbol{g}_2)\, dx$ calculable in lattice QCD
- expected error on $\boldsymbol{d}_2$ (Q^2 = 2.5 to 6.5 GeV^2) = 0.0009 (½ the current world error)
- Test of polarized local duality with ΔW resolution ≤ 130 MeV, constant Q^2

Estimated Systematics for 6 GeV

Radiative Corrections	1.5%
Dilution Factor	2.0%
Target Polarization	2.5%
Beam Polarization	1.0%
Nitrogen Correction	0.4%

	A1p		g2	
	x=0.3	x=0.6	x=0.3	x=0.6
R	0.8%	1.2%	1.5%	1.3%
Kinematics	0.4%	0.5%	2.7%	4.5%
Background	1.0%	1.0%	3.7%	1.8%
Local	2.1%	2.3%	4.0%	4.1%
Global	3.3%	3.3%	4.6%	4.7%
Total	4.2%	4.0%	6.8%	6.7%

Beam Time Request

	Energy	θ_N	Time (h)	
Production	6.0	180	100	
	6.0	80	200	
	4.8	180	70	
	4.8	80	130	
	2.4	-	10	
Systematics	Packing Fraction		20	
	Mollers		21	
	Total beam time		551	(23 d)
Overhead	Anneals		62	
	Energy Change		48	
	Target Rotation		48	
	Stick Changes		48	
	Total Overhead		206	(9 d)
	Requested Time		654	(27 d)

PAC 24 Report

Individual Proposal Report

Proposal: PR 03-109

Scientific Rating: A-

Title: Spin Asymmetries on the Nucleon Experiment (SANE)

Monte Carlo simulations have also been performed to simulate the impact of the beam line background. Given the present expectations for the detector performance and for the background rate, the measurement should be feasible.

Issues: Due to the novel technique and to the uncertainties of the background in the measurement configuration, the PAC recommends that prior to the detector installation, experimental tests should be performed in order to verify the expected performances in terms of energy resolution and calibration, pion rejection and track reconstruction. In addition, the Collaboration should develop all the needed software and hardware tools to determine in the very early stage of the commissioning of the detector/polarized target set-up whether the background conditions and rates are in agreement with expectations.

Recommendation: Conditionally Approve for 27 days in Hall C

Collaboration (11/03)

J.-P. Chen, R. Ent, D. Gaskell, J. Gomez, D. Higinbotham, M. Jones,
D. Mack, J. Roche, G. Smith, B. Wojtsekhowski, S. Wood
Jefferson Lab

D. Crabb, D. Day, E. Frlez, N. Liyanage, P. McKee, D.Pocanic,
O. Rondon, F. Wesselmann, H. Zhu,
University of Virginia

E. Christy, C. Keppel
Hamption University

T. Averett
College of William and Mary

A. Vasiliev
Institute for High Energy Physics, Protvino

V. Kubarovsky
Rensselaer Polytechnic Institute

S. Choi, Z.-E. Meziani
Temple University

J. Jourdan, M. Kotulla, D. Rohe
University of Basel, Switzerland

A. Agalaryan, R. Asaturyan, H. Mkrtchyan, S. Stepanyan, V. Tadevosyan
Yerevan Physics Institute, Armenia

Spin Structure Physics
- → JLab, Temple, UVa,W&M

Detectors
- → Yerevan, JLab (LA Tech)

Calorimeter
- → Protvino, UVA, Temple

Target
- → JLab, UVA

Physics from SANE